

Data Science Training Webinars
Spatiotemporal Simulation

Application of Garin-Lowry Model in Simulating Urban Population and Employment Patterns

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Geographic Analysis**
Harvard University



**Geo-computation
Center for Social
Sciences**
Wuhan University



China Data Institute



Future Data Lab

Contents

□ Introduction

- Research background
- Literature review
- Line of thought

□ Methodology

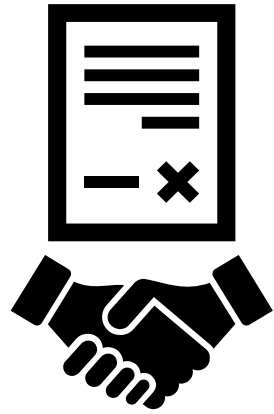
- The Garin-Lowry model
- Solving a system of linear equations

□ Case study

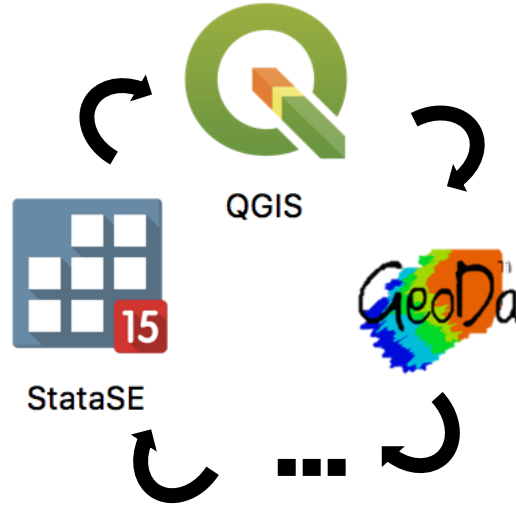
- Technologic flow
- Workflow implementation
- Step by step workflow execution

□ Conclusion and discussion

Research Background



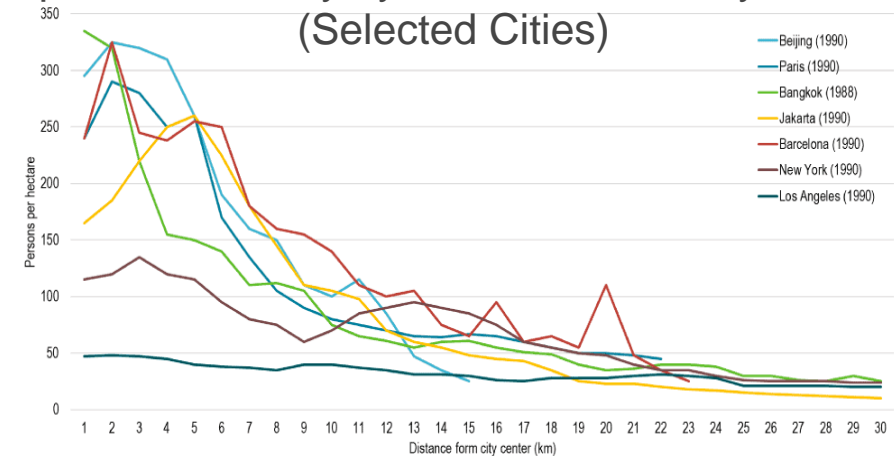
Data



Technology



Population Density by Distance from City Center
(Selected Cities)



Simulation comparison of different scenarios

Literature Review

Urban Spatial Structure

land use

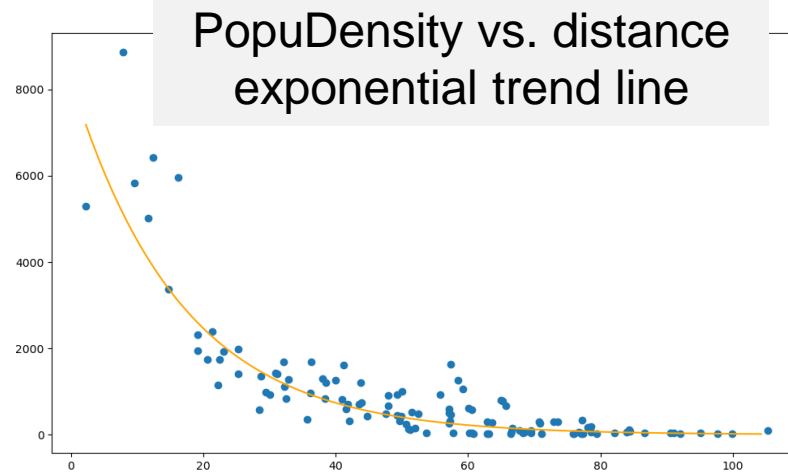
population spatial structure

traffic network

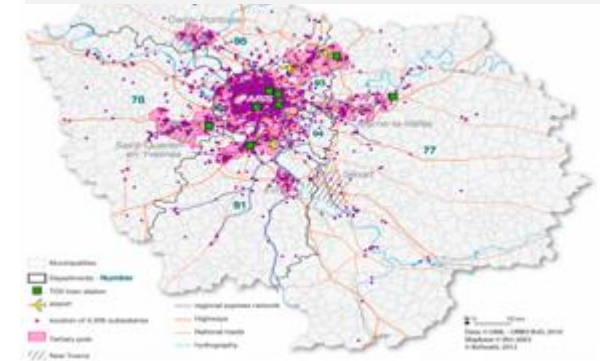
green space water area

...

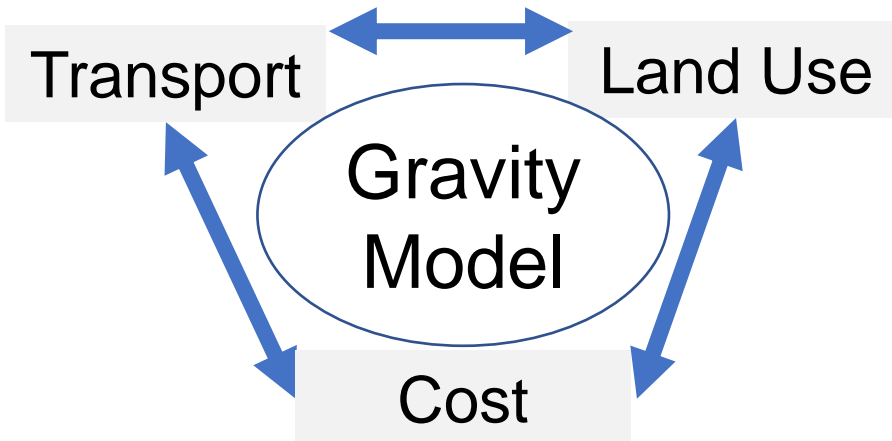
Static urban spatial structure



Location of multinational subsidiaries in the Paris

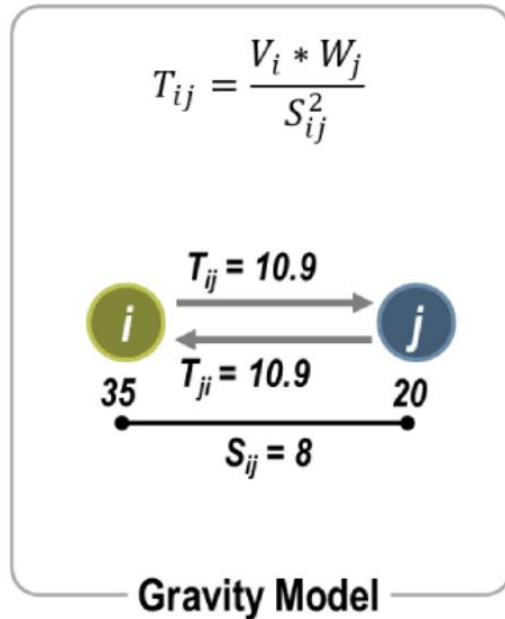


Dynamic urban spatial structure



Literature Review

□ Spatial Interaction Model



From unique case studies
to multi-scenario simulations

□ Lowry Model

- A **urban simulating model** of the spatial organization of human activities within a metropolitan area.
- Predict changes in **metropolitan form**:
 - the pattern of **employment**
 - the growth of **population**
 - the efficiency of transportation system

nonlinear
optimization

□ Garin-Lowry Model

$$y_2 = y_1 A_1 + x_2$$

Line of Thought

Data Collection

Data Curation

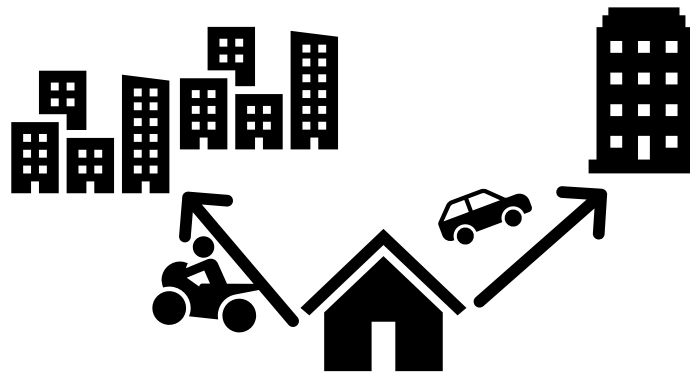
Model Simulation



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- Study area: N tracts & Connected

- Basic employment distribution



- Travel time

- Manually set the parameter variation range



Visualization

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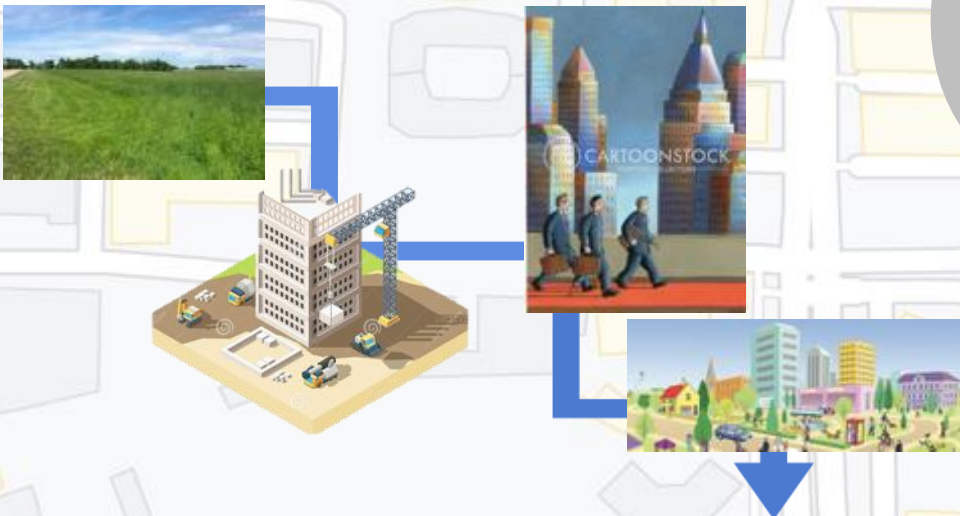
□ Conclusion and discussion

The Garin-Lowry Model

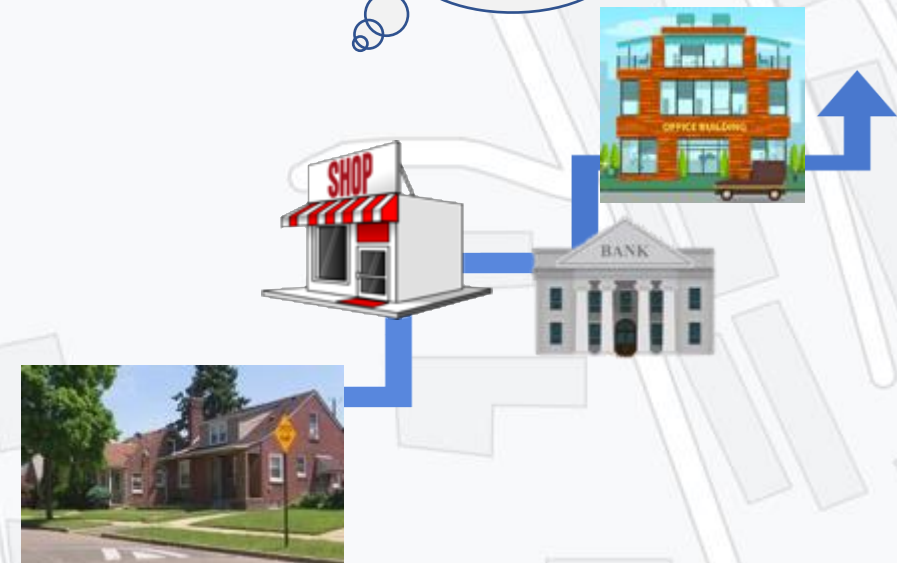
□ Basic Hypothesis

Population and employment distributions **interact** with each other and are **interdependent**.

I. Population follows employment



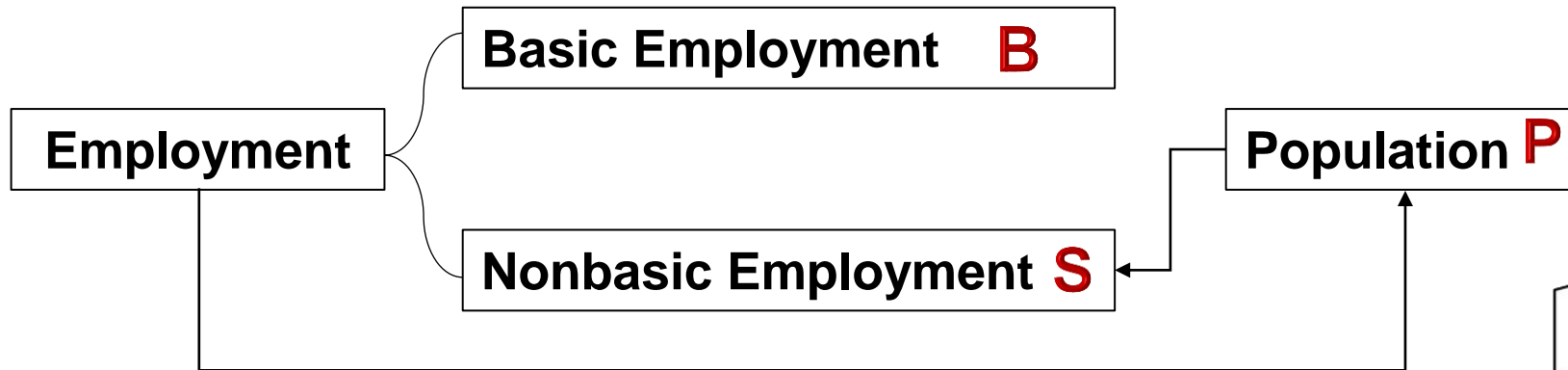
II. Employment follows population



The Garin-Lowry Model

□ Basic Hypothesis

- Basic Employment: independent
- Nonbasic/Service Employment: follows the distribution of residential population.



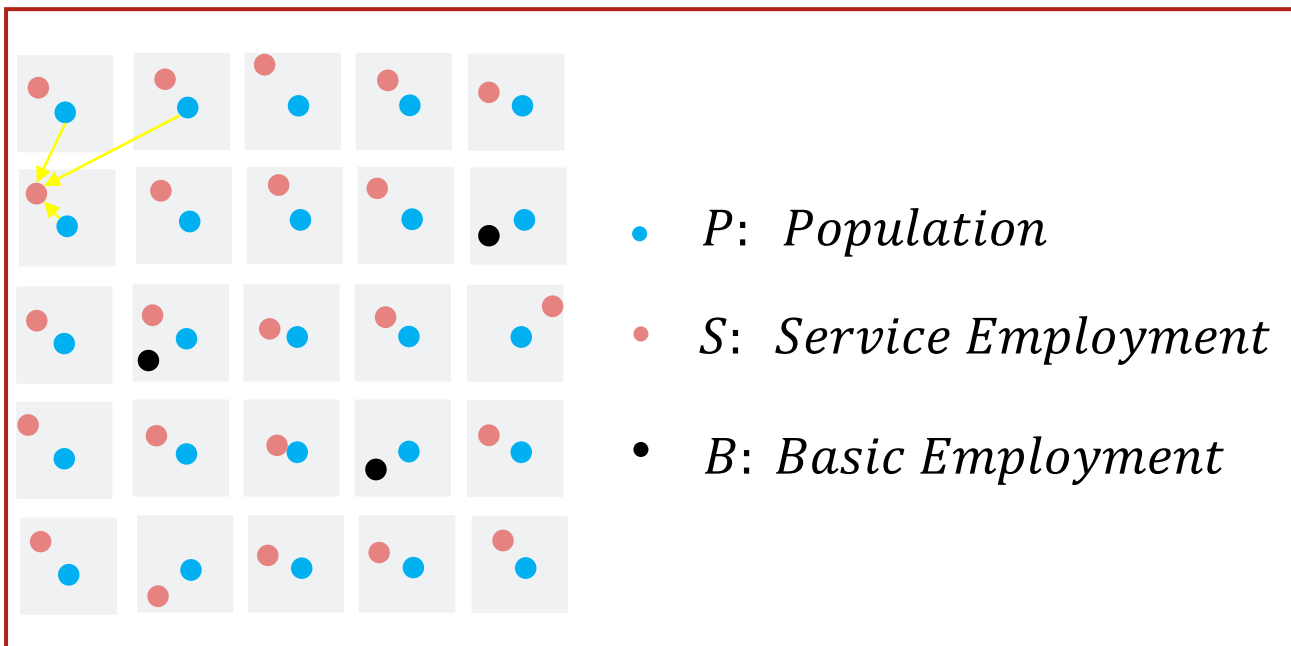
Interaction between population and employment distributions in a city



The Garin-Lowry Model

$$S = TP \quad S_i = e \sum_{j=1}^n (P_j t_{ij}) = e \sum_{j=1}^n [P_j (d_{ij}^{-\alpha} / \sum_{l=1}^n d_{lj}^{-\alpha})]$$

$$P = GS + GB \quad P_i = h \sum_{i=1}^n (E_i g_{ij}) = h \sum_{i=1}^n [(B_i + S_i) (d_{ij}^{-\beta} / \sum_{k=1}^n d_{ik}^{-\beta})]$$



$$e = \frac{\text{Service Employment}}{\text{Population}}$$

$$h = \frac{\text{Population}}{\text{Employment}}$$

d_{ij} : the distance between i and j , ($i | j = 1, 2, \dots, n$)

α : the distance friction coefficient
(resident – service)

β : the distance friction coefficient
(resident – workplace)

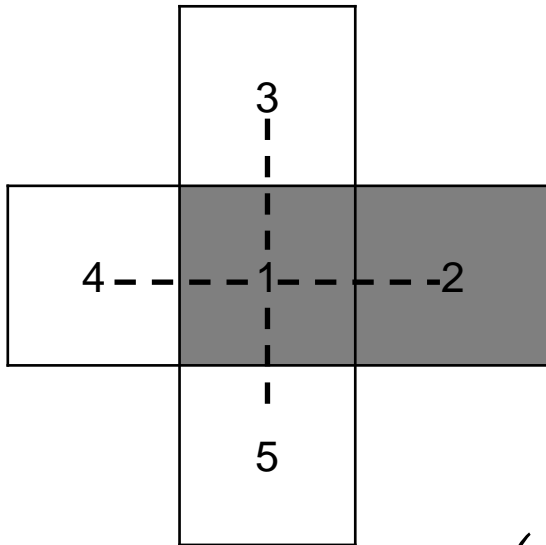
The Garin-Lowry Model

$$\mathbf{S} = \mathbf{TP}$$

$$S_i = e \sum_{j=1}^n (P_j t_{ij}) = e \sum_{j=1}^n [P_j (d_{ij}^{-\alpha} / \sum_{l=1}^n d_{lj}^{-\alpha})]$$

$$\mathbf{P} = \mathbf{GS} + \mathbf{GB}$$

$$P_i = h \sum_{i=1}^n (E_i g_{ij}) = h \sum_{i=1}^n [(B_i + S_i) (d_{ij}^{-\beta} / \sum_{k=1}^n d_{ik}^{-\beta})]$$



- $B_1 = 1, B_2 = B_3 = B_4 = B_5 = 0$
- $d_{1j}=1, d_{ij}=0.25$
- $h=2.0, e=0.3, \alpha = 1.0, \beta = 1.0$



$$S_1 = 0.3 \left(\frac{d_{11}^{-1}}{d_{11}^{-1} + d_{21}^{-1} + d_{31}^{-1} + d_{41}^{-1} + d_{51}^{-1}} P_1 + \frac{d_{12}^{-1}}{d_{12}^{-1} + d_{22}^{-1} + d_{32}^{-1} + d_{42}^{-1} + d_{52}^{-1}} P_2 * 4 \right)$$

Solving A System of Linear Equations

□ LU-factorization

- the forward substitution algorithm is used to solve the system

$$\begin{bmatrix} a_{11} & 0 & \cdots & 0 \\ a_{21} & a_{22} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} = \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_n \end{bmatrix}$$

- the back substitution algorithm is used to solve the system

$$\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ 0 & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & a_{nn} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} = \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_n \end{bmatrix}$$

$$\begin{cases} S_1 = 0.1500P_1 + 0.1846P_2 \\ S_2 = 0.0375P_1 + 0.2538P_2 \\ P_1 = S_1 + 1.2308S_2 + 1 \\ P_2 = 0.25S_1 + 1.6823S_2 + 0.25 \end{cases} \quad Ax = b$$

$$\begin{bmatrix} -1 & 0 & 0.15 & 0.1846 \\ 0 & -1 & 0.0375 & 0.2538 \\ 1 & 1.2308 & -1 & 0 \\ 0.25 & 1.6823 & 0 & -1 \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \\ P_1 \\ P_2 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ -1 \\ -0.25 \end{bmatrix}$$

$$A = LU$$

$$Lz = b$$

$$Ux = z$$

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ -0.25 & 1 & 0 & 0 \\ -1 & 0.7316 & 1 & 0 \\ 0 & -0.5944 & -0.0681 & 1 \end{bmatrix}$$

$$\begin{bmatrix} -1 & 0 & 0.15 & 0.1846 \\ 0 & 1.6823 & 0.0375 & -0.9539 \\ 0 & 0 & -0.8774 & 0.8825 \\ 0 & 0 & 0 & -0.2531 \end{bmatrix}$$

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□ Case study

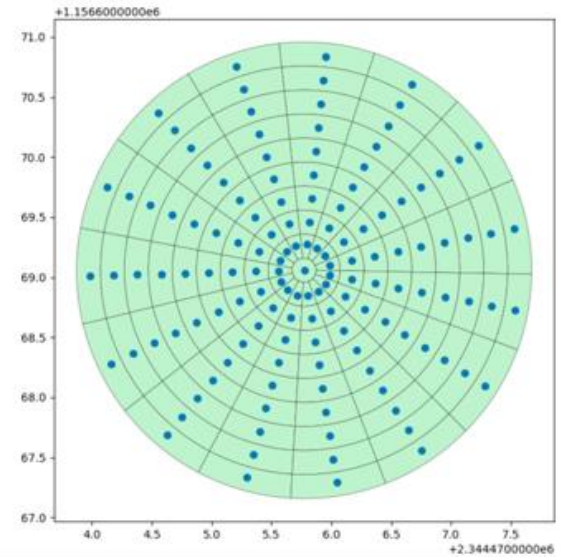
- Technologic flow
- Workflow implementation
- Step by step workflow execution

□ Conclusion and discussion

Case Study

□ **Study area:** A Hypothetical City

□ **Data**



Shapefile	Type	File Detail	Key Fields	Key Variable	Data Source
tract	Polygon	Base map for plotting			The case study is built upon the work reported in Wang (1998), but revised extensively for clarity of illustration.
trtpt	Point	Study area centroids	BEMP_CBD BEMP_UNIF	Basic employment per region: single center uniform distribution	
road	line	The hypothetical city is here assumed to be partitioned by a transportation network made of 10 circular rings and 15 radial roads.	LENGTH LENGTH1	Length of each road segment	

Technologic Flow

Data Input

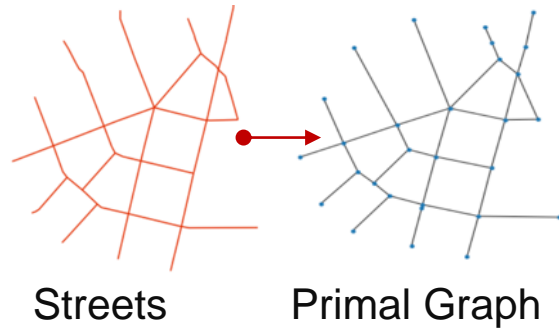
Road

Tract Point

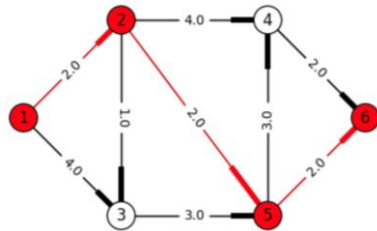
Tract

Data Preprocessing

Create a network dataset



OD Cost Matrix

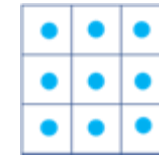


Distributions

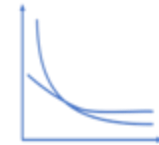
Garin – Lowry Model



The basic case
(Monocentric)



A uniform distribution



travel friction
coefficients (α | β)



transportation network

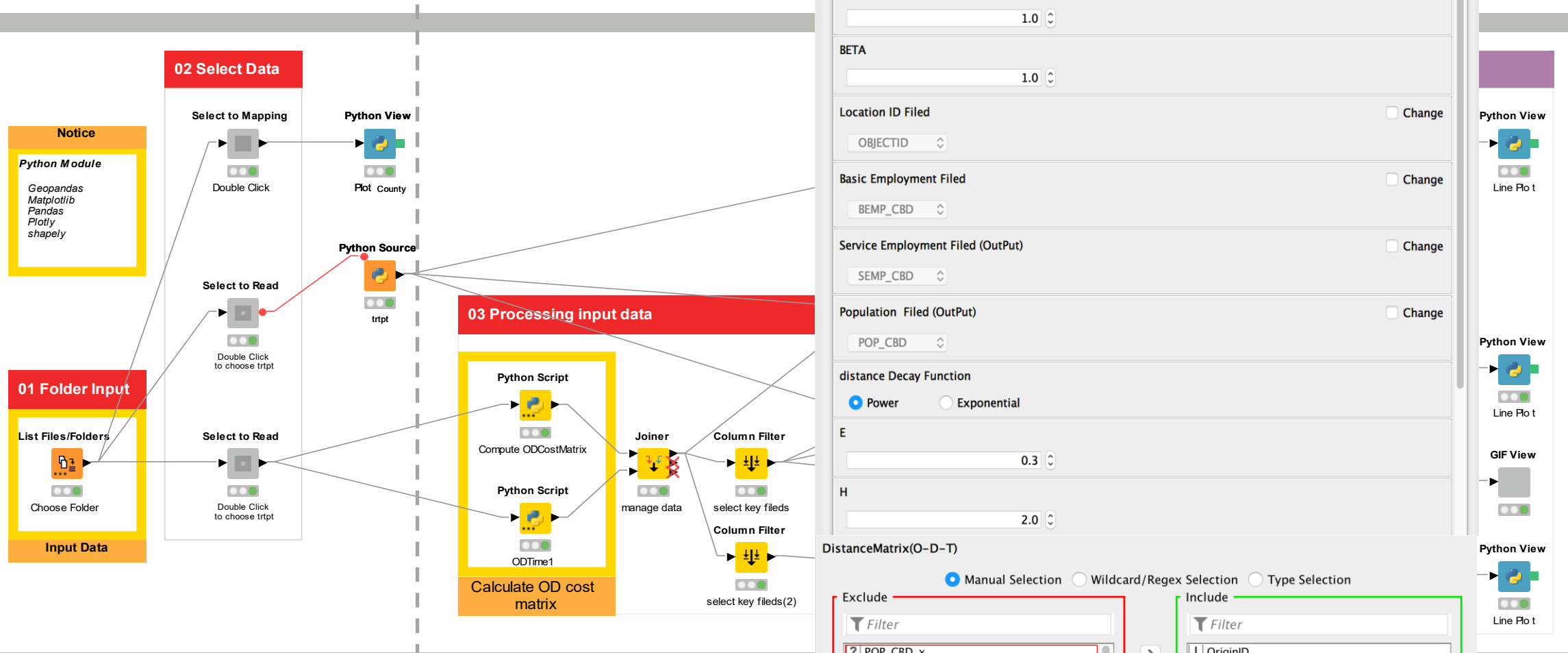
Compared

Population
distributions
in various
scenarios

Service
employment
distributions
in various
scenarios

The Workflow Implementation

Chapter 10 System of Linear Equations and Application of Garin-Lowry Model in Simulating Urban Population and
Case Study 10 Simulating Population and Service Employment Distrib

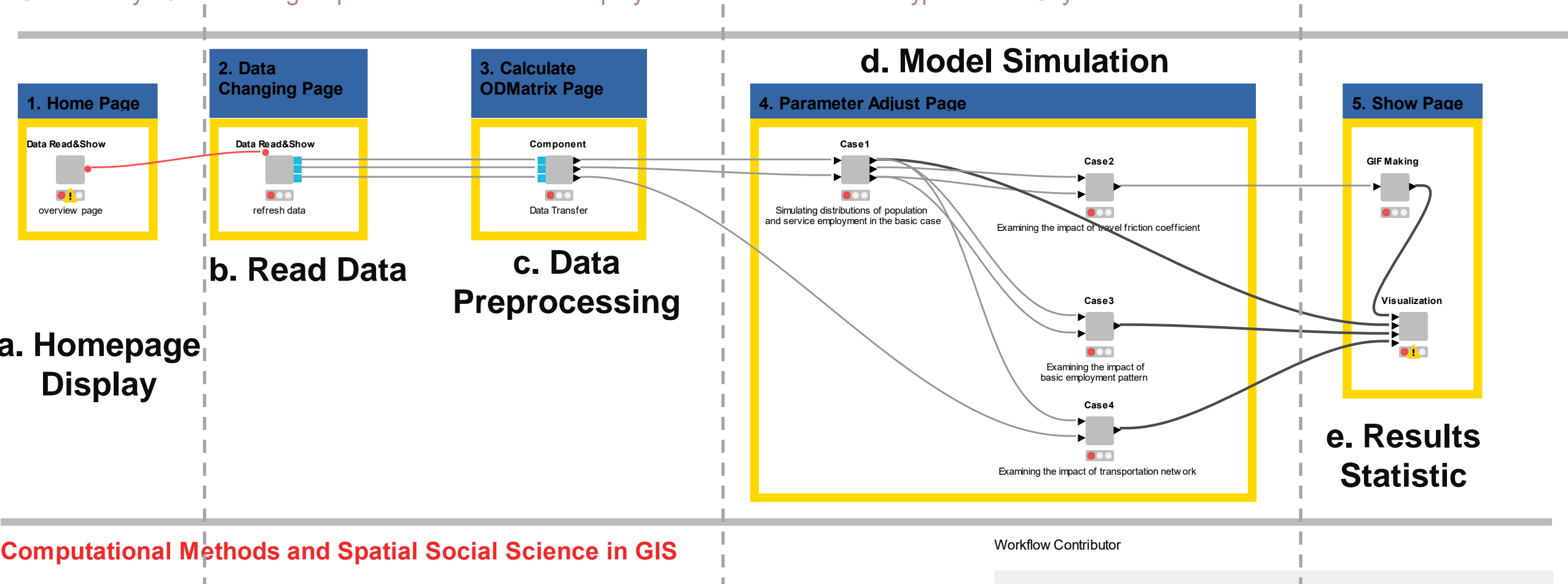


Computational Methods and Spatial Social Science in GIS

The Workflow Implementation

Chapter 10 System of Linear Equations and Application of Garin-Lowry Model in Simulating Urban Population and Employment Patterns

Case Study 10 Simulating Population and Service Employment Distributions in a Hypothetical City



Computational Methods and Spatial Social Science in GIS

Workflow Contributor

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Step by Step Workflow Execution I

a. Homepage Display

Home > lingbo > Chapter10_Final_web0521_postil > Chapter10_Final_web0521_postil 2022-05-30 02.09.08



Chapter 10: System of Linear Equations and Application of Garin-Lowry Model in Simulating Urban Population and Employment Patterns

This chapter introduces the method for solving a system of linear equations (SLE). The method is fundamental in numerical analysis (NA), and is often used as a building block in other NA tasks such as solving a system of nonlinear equations and the eigenvalue problem. Here, the SLE is illustrated in the Garin-Lowry model, a model widely used by urban planners and geographers for analyzing urban land use structure.

There has been an interesting debate on the relation between population and employment distributions in a city. Does population follow employment (i.e., workers find residences near their workplaces to save commuting)? Or vice versa (i.e., businesses locate near residents for recruiting workforce or providing services)? The Garin-Lowry model argues that population and employment distributions interact with each other and are interdependent. The Garin-Lowry model has the flexibility of simulating a population distribution pattern corresponding to any given basic employment pattern. It can be used to examine the impact of basic employment distribution on population as well as that of transportation network.

Title: Simulating Population and Service Employment Distributions in a Hypothetical City.

Objectives

Showing how the distributions of population and employment interact with each other and how the patterns can be affected by various transportation networks.

Methodology

LU-factorization & Garin - Lowry Model

Data

The project primarily uses the file geodatabase SimuCity.gdb under the folder SimuCity, which contains: (1) a polygon feature (136 tracts): tract.shp

Step by Step Workflow Execution II

b. Read Data

The screenshot shows a web application interface for data monitoring. At the top, there is a blue header with a globe icon, a play button, and the text "Monitoring". Below the header is a breadcrumb trail: "Home > Users > workbook02 > Chapter10_Final_web0327_2 > Chapter10_Final_web0327_2 2022-03-27 08.07.20".

The main content area is divided into three columns, each with an upload section and a data visualization section:

- Left Column:** A "Refresh" button is at the top. Below it are the labels "Road data" and a link "Road data sample". The visualization is titled "Road" and shows a circular grid of latitude and longitude lines.
- Middle Column:** An "Upload tract shp file" section with a "Select file" button and the filename "tract.shp". Below it are the labels "tract data" and a link "tract data sample". The visualization is titled "tract" and shows a solid blue circular area.
- Right Column:** An "Upload road shp file" section with a "Select file" button and the filename "road.shp". Below it are the labels "trtp data" and a link "trtp data sample". The visualization is titled "trtp" and shows a circular area with a radial pattern of blue dots.

On the right side of the interface, there are two "Data Read&Show" panels. The first panel, highlighted with a yellow border, is labeled "overview page" and contains a grey square icon with a yellow warning triangle. The second panel, highlighted with a red border, is labeled "refresh data" and contains a grey square icon with a red dot. A red line connects the red dot in the second panel to the grey square in the first panel.

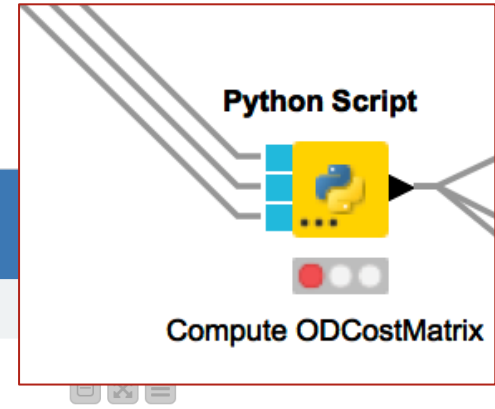
At the bottom right, there are "Cancel" and "Next" buttons.

Step by Step Workflow Execution II

c. Data Preprocessing

Monitoring

Home > Users > workbook02 > Chapter10_Final_web0327_2 > Chapter10_Final_web0327_2 2022-03-27 08.07.20



Compute ODCostMatrix

O-D-T

Show 10 entries

Search:

<input type="checkbox"/>	RowID	OriginID	Destinatio	NetwkTime	NetwkTime1
<input type="checkbox"/>	0	1	1	0.9643491637846165	0.9643491637846165
<input type="checkbox"/>	1	1	2	1.157446947088816	1.1574469530684135
<input type="checkbox"/>	2	1	3	1.4931367129593789	1.4931367072868116
<input type="checkbox"/>	3	1	4	1.5278273244853613	1.5278273305005134
<input type="checkbox"/>	4	1	5	1.357446925294658	1.3574469292933056
<input type="checkbox"/>	5	1	6	1.8793322851331424	1.8793322842835474
<input type="checkbox"/>	6	1	7	1.6931367186960218	1.6931367070670296
<input type="checkbox"/>	7	1	8	1.7051099196591724	1.6165121132094844
<input type="checkbox"/>	8	1	9	1.557446904629664	1.5574469071380814

← Back

Cancel

Next

Step by Step Workflow Execution III

d. Model Simulation

Home > lingbo > Chapter10_Final_web0521_postil > Chapter10_Final_web0521_postil 2022-05-30 01.33.42

Simulating distributions of population and service employment in the basic case

Adjust parameter options

Description of default options

The basic case, as in the monocentric model, assumes that all basic employment (say, 100) is concentrated at the CBD. The basic case assumes that $\alpha=1.0$ and $\beta=1.0$ for the two distance friction coefficients in the gravity kernels. Basic employment pattern is defined in the field BEMP_CBD with its value = 100 in the CBD tract and 0 elsewhere, and it saves the results, i.e., numbers of population and service employment, in the predefined fields *_POP and *_SEMP, respectively. Step 2 has already generated a different travel time data named NetwkTime.

Location ID Field	Basic Employment Field
OBJECTID	BEMP_CBD
ALPHA	BETA
1	1

Distance Field	H	E	distanceDecayFun
NetwkTime	2.0	0.3	Power

← Back Cancel **Next**

Component


Data Transfer

Case1

Simulating distributions of population and service employment in the basic case

Step by Step Workflow Execution III

d. Model Simulation

▶ Spatiotemporal Simulation... Monitoring ? 👤

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Examining the impact of basic employment pattern

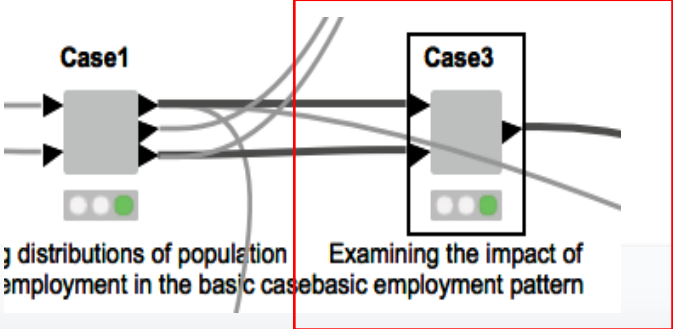
Adjust parameter options

Description of default options

To examine the impact of basic employment pattern, this project simulates the distributions of population and service employment given a uniform distribution of basic employment. In this case, all tracts have the same amount of basic employment, i.e., $100/136 = 0.7353$, which has been predefined in the field in BEMP_Unif. In parameter options, change the inputs for "Basic Employment Field" to BEMP_Unif. For the output, set "Output Service Employment Field" as *_Unif_SEMP set "Output Population Field" as *_Unif_POP.

Location ID Field

Basic Employment Field



Examining the impact of basic employment pattern

← Back Cancel Next

Step by Step Workflow Execution III

d. Model Simulation

Case: Examining the impact of travel friction coefficient

Adjust parameter options

Threshold
0.5

Min(ALPHA|BETA)
0.5

Max(ALPHA|BETA)
2.0

Description of default options

Keep all parameters in the basic case unchanged except the two travel friction coefficients α and β . Compared to the basic case where $\alpha = 1$ and $\beta = 1$, this new case realizes the sensitivity analysis of travel friction coefficients by setting the maximum and minimum values of α and β and the threshold size of each change. In parameter options, set ALPHA as 2, BETA as 2 and threshold as 0.5. For the output, "Output Service Employment Fields" and "Output Population Fields" will be created automatically.

Case1
Simulating distributions of population and service employment in the basic case

Case2
Examining the impact of travel friction coefficient

← Back | Cancel | Next

Step by Step Workflow Execution III

d. Model Simulation

Home > lingbo > Chapter10_Final_web0521_postil > Chapter10_Final_web0521_postil 2022-05-30 01.33.42

Examining the impact of transportation network

Adjust parameter options

Description of default options

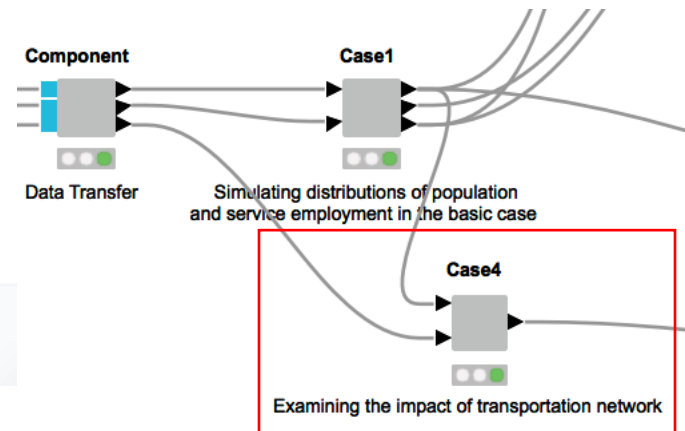
Examining the impact of transportation network, in this particular case, the building of a suburban beltway. Step 2 has already generated a different travel time data named NetwkTime1. For the output, set "Output Service Employment Field" as *_SEMP_Belt, "Output Population Field" as *_POP_Belt.

Location ID Field

Basic Employment Field

Distance Field

NetwkTime1



← Back

Cancel

Next

Step by Step Workflow Execution IV

e. Results Statistic



Spatiotemporal Simulation...

Monitoring

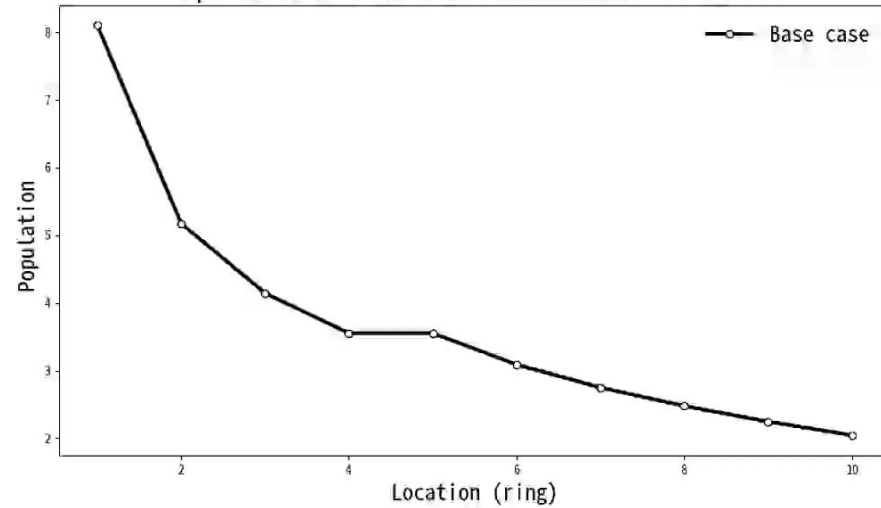


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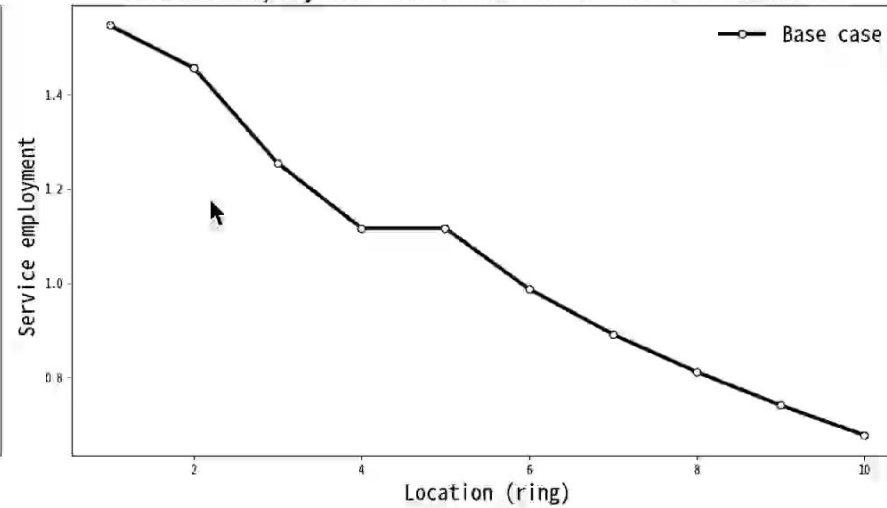


Case: Simulating distributions of population and service employment in the basic case

Population distributions in various scenarios



Service employment distributions in various scenarios



← Back

Delete this result

Close

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□ Conclusion and discussion

Conclusion

- ❑ The model is constructed as a system of linear equations, which is easy to calculate.
- ❑ The case study used a hypothetical city helps us understand the change of urban structure under various scenarios and explain many empirical observations in urban density studies.
- ❑ The distribution of service employment and population under **different distance friction coefficients** is **simulated**.

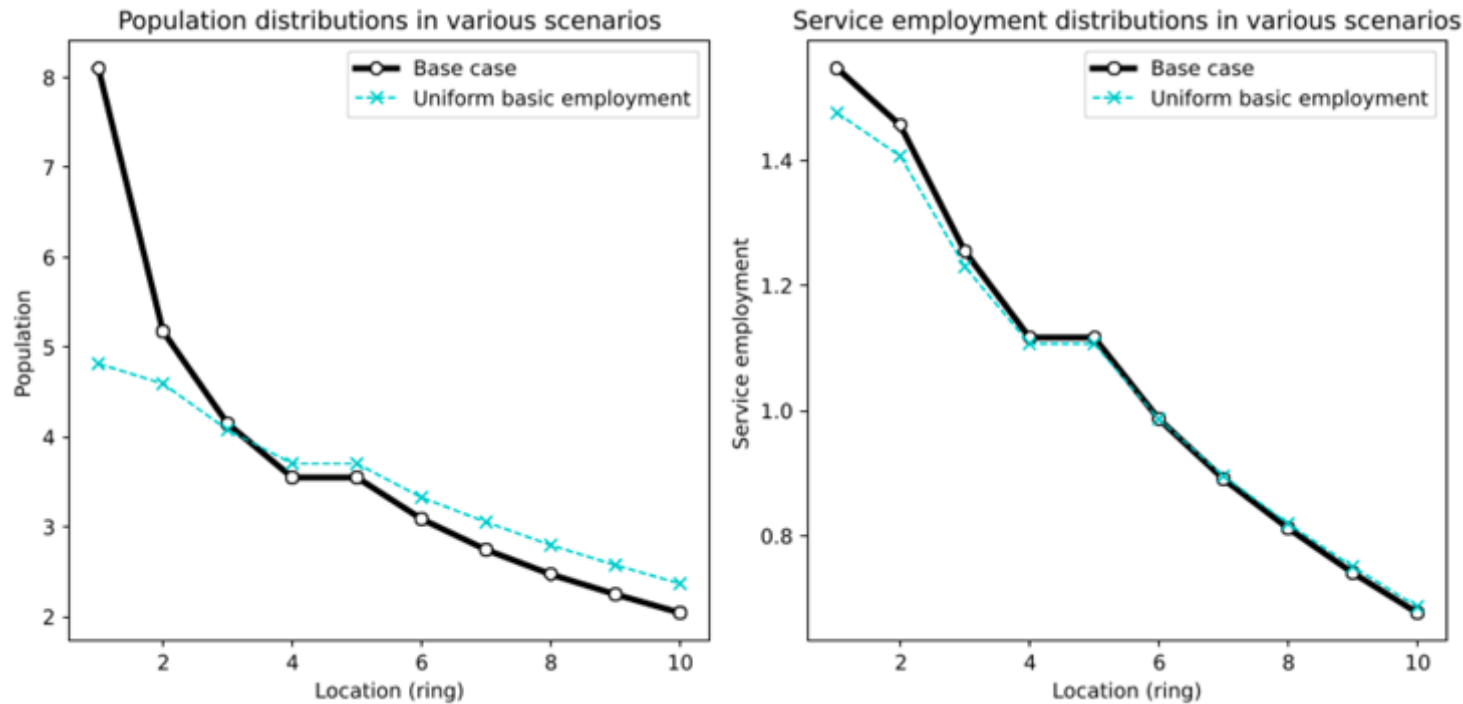
Discussion

□ Comparison of different basic employment distributions

Case1: Simulating distributions of population and service employment in the basic case

VS

Case2: Examining the impact of basic employment pattern



- both the population and service employment remain **declining from the city**.
- both the population and service employment **exhibit steeper slopes** in the basic case than case2.

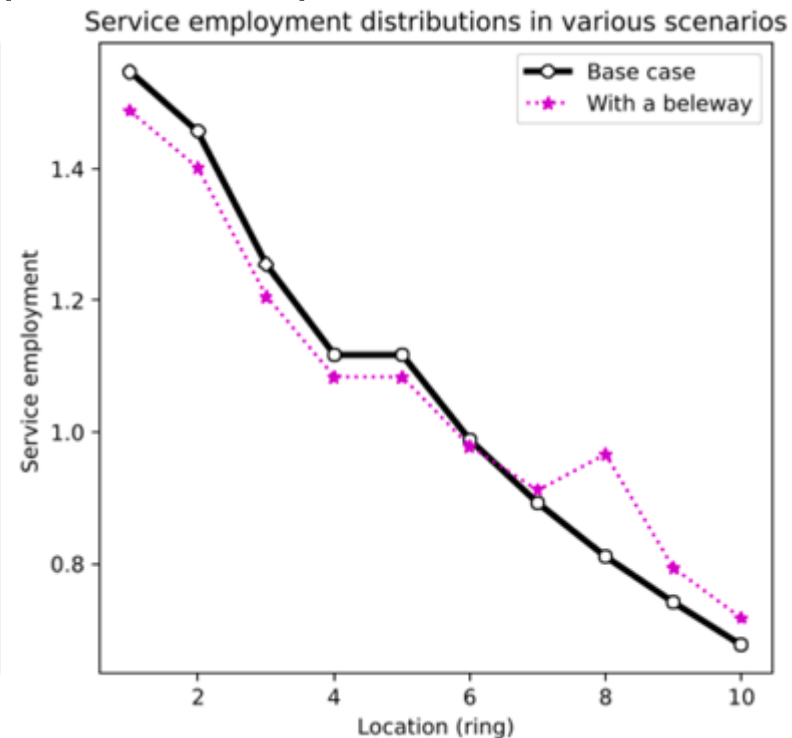
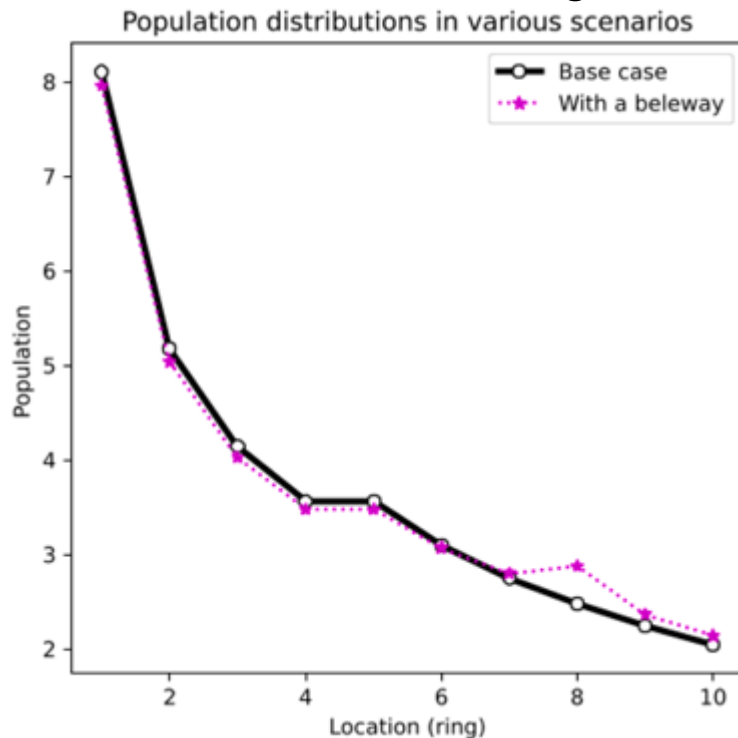
Discussion

□ Comparison of different transportation network

Case1: Simulating distributions of population and service employment in the basic case

VS

Case4: Examining the impact of transportation network



- The distribution patterns of population and service employment are **similar** to those in the basic case.
- The lower values before the 7th ring
- The higher values after the 7th ring

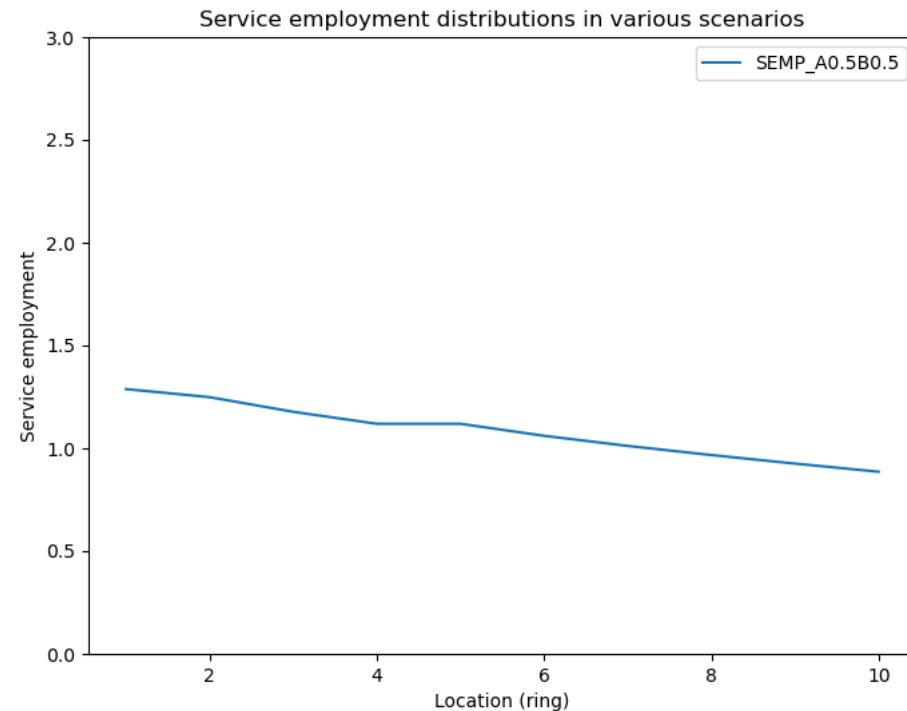
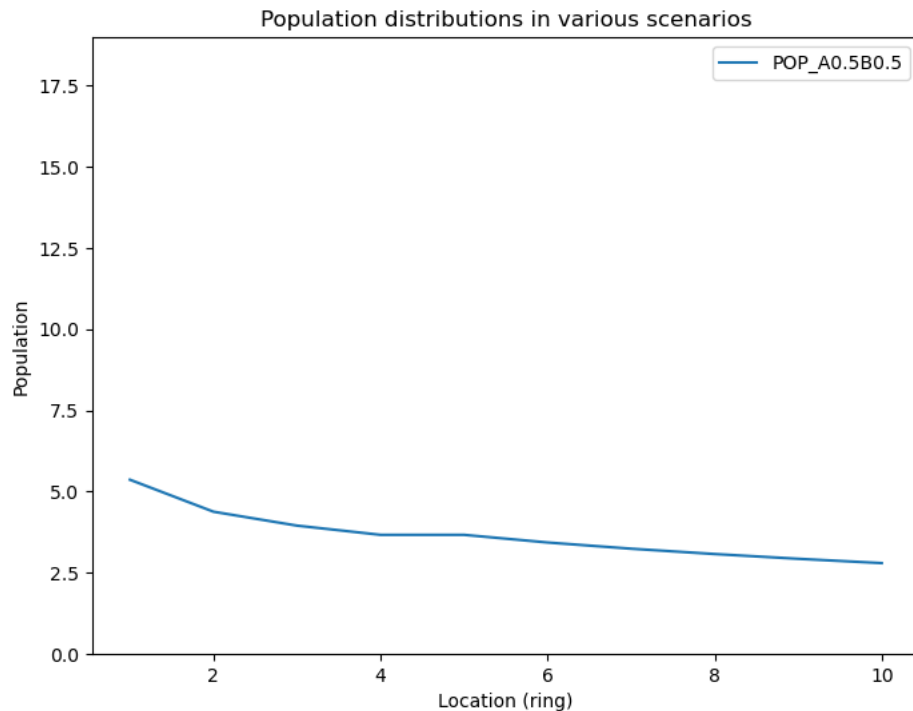
Discussion

□ Comparison of different distance friction coefficient

Case1: Simulating distributions of population and service employment in the basic case

VS

Case3: Examining the impact of travel friction coefficient



- The **steeper slopes** for both population and service employment in case3 with larger α and β .

Future Work

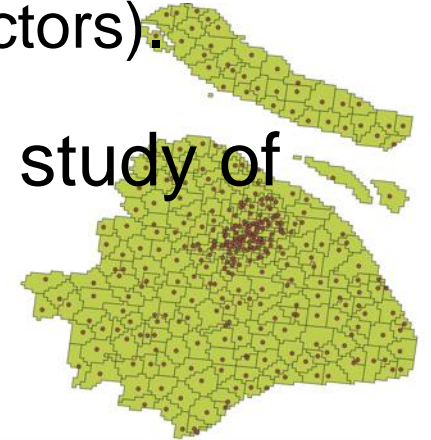
- Applying the Garin-Lowry model in analyzing real-world cities:
(required the division of employment into basic and nonbasic sectors).

- The model may be used to examine more issues in the study of urban structure:

 - the impact of road density;

 - the impact of road network structure;

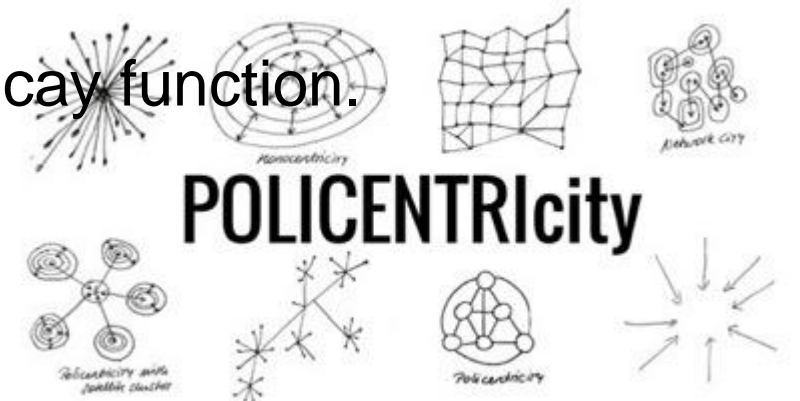
 - exploring population and employment in polycentric cities.



- Model modification:

 - The challenges of defining a realistic distance decay function.

- ...



References

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